May 1999 • NREL/ TP-540-26035

Technical Report

Barwood CNG Cab Fleet Study

Final Results

Peg Whalen, Ken Kelly, and Mardi John

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393

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List of Acronyms and Abbreviations

AFV	Alternative fuel vehicle
ANOVA	Analysis of variance
AQIRP	Auto/Oil Air Quality Improvement Research Program
CH_3CHO	Acetaldehyde
CH_4	Methane
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
DOE	Department of Energy
EPA	Environmental Protection Agency
ERD	Environmental Research & Development
FTP-75	Federal Test Procedure
GGE	Gasoline gallon equivalent
HC	Hydrocarbons
HCHO	Formaldehyde
HWFET	Highway fuel economy test
ILEV	Inherently low emission vehicle
MPG	Miles per gallon
NMHC	Non-methane hydrocarbons
NO_X	Oxides of nitrogen
NREL	National Renewable Energy Laboratory
RFG	Reformulated gasoline
RVP	Reid vapor pressure
THC	Total hydrocarbons
UDDS	Urban dynamometer driving schedule
ULEV	Ultra-low emission vehicle

Abstract

This report describes a fleet study conducted over a 12-month period to evaluate the operation of dedicated compressed natural gas (CNG) Ford Crown Victoria sedans in a taxicab fleet. In the study, we assessed the performance and reliability of the vehicles and the cost of operating the CNG vehicles compared to gasoline vehicles. The study included 10 dedicated CNG and 10 gasoline-only Crown Victoria sedans; all were from the 1996 model year. The evaluation included collecting and analyzing detailed operating and maintenance records and cost data, along with performing a series of emissions tests at selected mileage intervals (60,000; 90,000; and 120,000).

The study results reveal that the CNG vehicles operated by this fleet offer both economic and environmental advantages. The total operating costs of the CNG vehicles were about 25% lower than those of the gasoline vehicles. The CNG vehicles were operated in the same service, and were maintained according to the same schedule as the gasoline vehicles. The CNG vehicles performed as well as the gasoline vehicles, and were just as reliable. Emissions testing results confirmed that the exhaust emissions of dedicated CNG vehicles tend to be significantly lower than their gasoline counterparts. In addition, this study is the first to confirm that these benefits can be maintained in real-world service throughout the useful life (100,000 miles) of the vehicle and beyond. The emissions results also tend to indicate that emissions from CNG vehicles may deteriorate less quickly (with mileage) than similar gasoline vehicles. Any concerns the fleet's drivers and maintenance staff may have had about operating or maintaining the CNG vehicles are gone, and they consider the CNG vehicles to be just like any other vehicle. Cab company representatives have come to consider the CNG vehicles an asset to their business and to the air quality of the community.

Introduction

As part of efforts to reduce national dependence on imported oil and to improve urban air quality, the U.S. Department of Energy (DOE) is promoting the development and deployment of alternative fuels and alternative fuel vehicles (AFVs). To support these activities, DOE directed its National Renewable Energy Laboratory (NREL) to develop and conduct projects to evaluate the performance and acceptability of light-duty AFVs compared to similar gasoline vehicles. NREL has undertaken a number of evaluation projects, including several fleet study projects, which seek to provide objective information on real-world fleet experiences with AFVs.

This fleet study was designed to evaluate the operation of dedicated compressed natural gas (CNG) Ford Crown Victoria sedans in a taxicab fleet. The project goals were to evaluate the cost of operating AFVs compared to gasoline vehicles, and to assess the performance and reliability of the vehicles. In this type of evaluation effort, we collect and analyze detailed operating and maintenance records and cost data. Ideally, a study fleet would accumulate high annual mileage (50,000 miles or more per study vehicle) to shorten the data collection period. High mileage accumulation also would enable the data collection effort to include emissions testing on the study vehicles (at two or three mileage intervals).

Project Participants

Completing this focus fleet study required the cooperation and support of several participants. Here are the participants and their roles:

- *Barwood Cab Company*: Barwood served as the host fleet for the study. The company purchased 10 1996 CNG Crown Victorias, and operated them in the same service as its1996 gasoline-only Crown Victorias. Barwood also provided access to all vehicle maintenance records and all available fueling records. (Barwood received funding from the local natural gas company to offset the incremental cost difference of the CNG vehicles).
- *Mardi John*: Working under contract to NREL, Ms. John was responsible for working directly with the fleet to collect all the operating and maintenance data and cost information. She also developed appropriate database tables for the data, and submitted the data to NREL.
- *Environmental Research & Development* (ERD): ERD was the emissions test facility NREL contracted to conduct the emissions testing in this project. ERD worked with the fleet to test the study vehicles at selected mileage intervals.
- *U.S. Department of Energy*: DOE provided the funding for the data collection, emissions testing, data analysis, and reporting.
- *National Renewable Energy Laboratory*: NREL coordinated and managed the project. NREL also provided the appropriate expertise to conduct the data analysis and reporting on the project.

The project began during the summer of 1997, with data collection and emissions testing conducted over a 12-month period.

Fleet Information and Operations

Barwood Incorporated, the official name of the cab company, is a privately held, family-owned company that has been in business for more than 30 years. Barwood is based in Kensington, Maryland (see Figure 1), and operates a fleet of about 400 vehicles, serving some 5,000 customers daily. Approximately 90% of the cabs in the Barwood fleet are Ford Crown Victorias, and all are no more than 5 years old.

Each cab is typically assigned to an individual driver based on seniority, safety record, and customer service record. The drivers work as independent contractors and pay daily rent for using their vehicles. The drivers are also responsible for keeping their vehicles clean, bringing them in for regular servicing (according to a mileage schedule), and paying for their own fuel. Most of the study vehicles had more than one driver during the course of the study.

Typically, the drivers work 6 days a week, averaging 5 to 12 short trips (about 4 miles each), and 5 to 15 longer trips (about 21 miles each) per day. Approximately two-thirds of the trips are city-type driving and one-third of the trips are highway driving.

Barwood owns and operates its own maintenance and repair facility, as well as its own 24-hour towing and emergency road service. This Barwood facility and its personnel are tasked with meeting all the vehicle maintenance and repair needs of the cab fleet.

Fueling

The 10 Barwood CNG vehicles are fueled using existing publicly accessible CNG stations. There is a Washington Gas station just down the street from the Barwood facility, which provided access to the

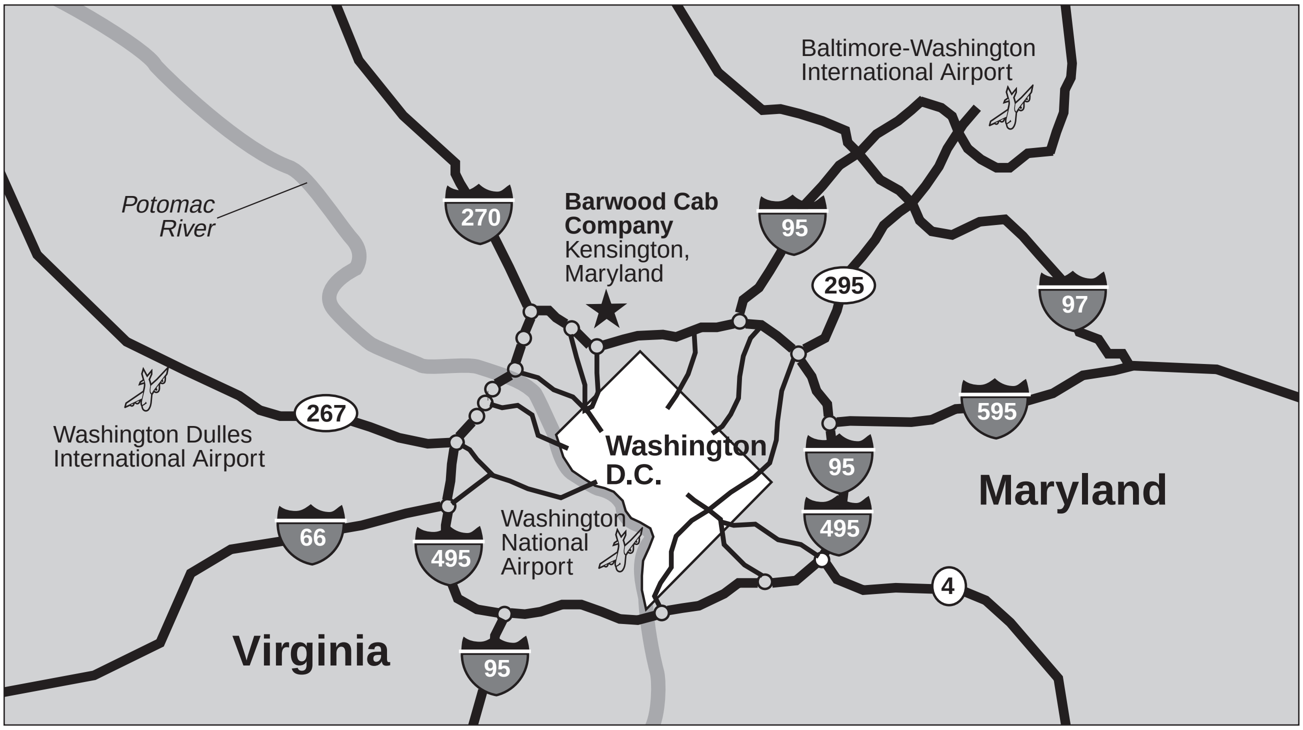

Figure 1. Location of Barwood fleet in surburban Maryland

Barwood fleet whenever it was open. The drivers used this facility as much as possible, but also used other public CNG stations throughout the metro DC area.

Data Collection

All the vehicles in the study were 1996 Ford Crown Victoria sedans: 10 were dedicated CNG models, and 10 were standard gasoline models. Table 1 summarizes the basic specifications of these vehicles (for more information on the CNG Crown Victoria, see Lapetz et al., 1995). The CNG vehicle uses a higher compression ratio, which takes advantage of the higher octane rating of CNG to improve efficiency. Other differences of note include the increased curb weight and reduced trunk space because of the CNG fuel tanks, and the reduced fuel capacity, which decreases the range of the vehicle.

Table 1. General Vehicle Specifications

	CNG Crown Victoria	Gasoline Crown Victoria
Engine	4.6L V8	4.6L V8
Engine Family Code	TFM4.6V8C7EK	TFM4.6V8GFEL
Fuel Capacity	10 gal (gasoline equiv.)	20 gal
Compression Ratio	10:1	9:1
Estimated mpg: City	17	17
Highway	25	25
Curb Weight	3814 lb	3780 lb
Trunk volume	14 cu ft	20.6 cu ft

The Barwood fleet

Operating and maintenance records and cost information were collected from all 20 vehicles over a 12-month period. In addition, emissions evaluations were conducted on 14 of 20 vehicles (7 CNG and 7 gasoline) at three high-mileage intervals. The following discussions provide more information on the operational data and emissions testing.

Operational Data

All maintenance and repair records for the study vehicles were obtained, including all scheduled and unscheduled maintenance and repairs. In addition, fueling records, including the amount of fuel used and odometer readings, were collected.

As previously mentioned, a subcontractor to NREL collected these various records. The contractor had experience with other alternative fuel vehicle projects. In addition, proximity to the Barwood fleet enabled the contractor to work closely with Barwood's director of driver services, manager of information systems, and the director of maintenance facility operations. A significant amount of time was spent working closely with the cab company's staff to clearly define the data requirements and to obtain data submissions. The Barwood facilities were visited about once a week from September 1997 through August 1998.

Barwood staff provided access to maintenance and repair records. The records were in two forms: spreadsheet summaries for each vehicle, and copies of actual work orders from vehicle servicing. A staff of mechanics at the cab company serviced the vehicles on site. The records collected included all maintenance and repair records from each vehicle, going back to when the study vehicles were put into service. The records included a description of the service or repair, the date and odometer reading at the time of the work, and a breakdown of costs associated with the service or repair.

The gas company assigned a credit card to each CNG cab, and was able to provide fuel records based on its use. The card (for a specific vehicle) was linked to a driver, so when Barwood assigned the vehicle to a driver, Washington Gas Company was able to track CNG fuel use and bill drivers for fuel. The gas company provided copies of the CNG vehicle refueling records to Barwood, which then supplied them to the contractor doing data collection. These records provide monthly totals of accumulated mileage, fuel use, and fuel cost by vehicle. At times, there were some discontinuities in these records, generally resulting from changes in the driver of a specific vehicle, or from drivers paying cash for their fuel rather than using the credit card. Often there was a delay in reassigning a fuel card to a new driver when a driver changed during any month (records during these periods would be unavailable). Drivers generally paid cash during these times. All data included in the fuel economy and cost analyses were from available records. Barwood also tracks vehicle mileage on at least a monthly basis, which provided a check on mileage accumulation for each of the study vehicles.

Barwood does not track fuel use in the gasoline vehicles because the drivers work as independent contractors, and are responsible for refueling and purchasing their own fuel. Although much time was spent working with the director of driver services to get complete and accurate records from the gasoline vehicle drivers, there was mixed success in getting "good" refueling records for the complete study period. By good, we mean complete and accurate records, including dates, odometer readings, fuel added, and fuel cost for each fill-up during each month. Our goal was to get 3 complete months of refueling records from each of the gasoline vehicles. We were able to achieve this for the three-month period from May through July 1998.

Emissions Testing

Three rounds of emissions tests were performed on seven CNG and seven gasoline control vehicles. The tests followed the EPA's Federal Test Procedure (FTP-75), which makes use of the urban dynamometer driving schedule (UDDS) for exhaust emissions, and includes two 1-hour evaporative tests. Additional details on the test procedures used for CNG vehicles can be found elsewhere (Kelly, 1996). Although CNG vehicles inherently do not have evaporative emissions, a modified evaporative test procedure was performed to determine if any gaseous fuel was escaping from the vehicles' fuel systems. The standard cold soak (diurnal) evaporative test was modified for the CNG vehicles in that the fuel tank was not heated over the 1-hour test period.

The tests were scheduled at odometer levels of 60,000 miles; 90,000 miles; and 120,000 miles. Figure 2 shows the distribution of actual test odometers over the three test rounds. Tests were completed on all seven CNG and gasoline vehicles at 60,000 miles and 90,000 miles, and all the study vehicles, except two of the CNG vehicles, at 120,000 miles. All but two of the scheduled tests, then, were completed during the study period of approximately 12 months. A lower mileage test would have been desirable, but the project did not begin early enough to conducts tests at mileage lower than about 60,000 miles. Two of each of the vehicle types (CNG and gasoline) were tested in duplicate during each of the test rounds (see Table 2).

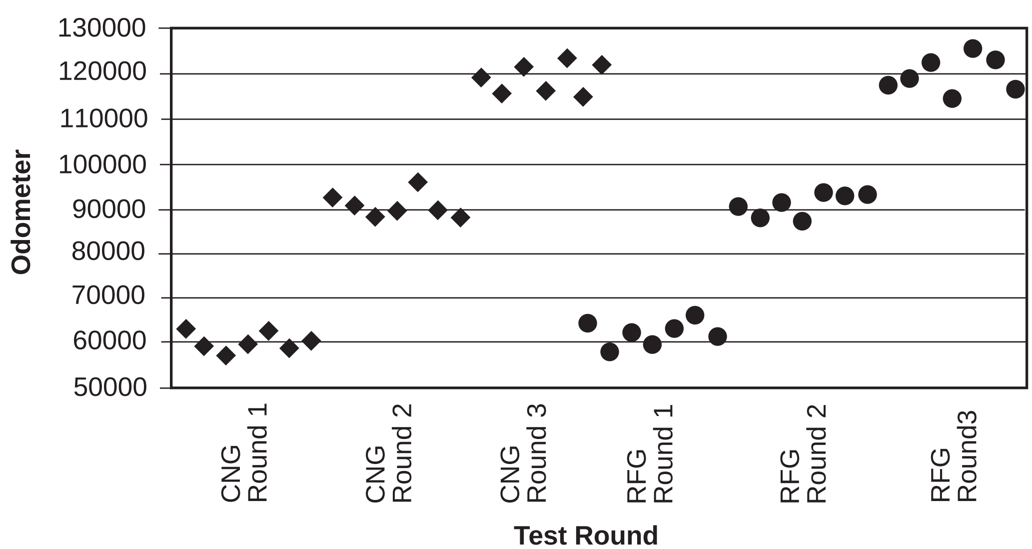

Figure 2. Distribution of study vehicle odometers for the three emissions test rounds

Table 2. Number of Emissions Tests

Test Round	Targeted Odometer (thousands of miles)	Vehicle Type	Vehicles Tested	Duplicate Tests	Total Tests
Round 1	60	CNG	7	2	9
		Gasoline	7	2	9
Round 2	90	CNG	7	2	9
		Gasoline	7	2	9
Round 3	120	CNG	7	2	9
		Gasoline	7	2	9

Both the CNG and the gasoline vehicles were tested on fuels that had been specially blended for the NREL emissions testing program. The CNG was blended to represent an industry-average fuel composition. The gasoline used was California Phase II reformulated gasoline (RFG). Tables 3 and 4 show the basic properties of these fuels. RFG was chosen as the baseline gasoline fuel in order to make a comparison of CNG with a “best-case” gasoline fuel. Other studies, such as that performed under the Auto/Oil Air Quality Improvement Research Program (AQIRP, 1994), provide comparisons between the emissions performance of RFG and industry-average gasoline.

The sets of duplicate test results were reviewed for repeatability, averaged, and then incorporated into the complete data set as a single test. Next, results from each emission constituent were reviewed for values outside a bound of the average plus or minus three standard deviations. The outliers defined in this way (shown shaded in the tables in Appendix A) were removed from the data set. After all checks and edits were applied, the data were imported into the JMP® software, which is a comprehensive PC-based statistical data analysis package developed by the SAS® Institute. Using this software, a multi-variable analysis of variance (ANOVA) was performed to determine the statistical significance of various factors on emissions. The primary effects of interest include fuel, vehicle, and test round. Secondary effects include the fuel-by-vehicle, fuel-by-test round, and vehicle-by-test round interactions. All data were analyzed at the 95% confidence level.

Table 3. CNG Test Fuel Specification and Analysis

Constituent	Specification (% volume)	Analysis (% volume)
Methane	93.05	93.15
Ethane	3.47	3.52
Nitrogen	1.67	1.47
Carbon Dioxide	0.81	0.82
Propane	0.66	0.68
N-Butane	0.12	0.13
I-Butane	0.08	0.07
N-Hexane	0.06	0.06
I-Pentane	0.04	0.06
N-Pentane	0.03	0.04
Oxygen	0.00	0.00

Table 4. Industry-Average and California Phase II RFG Properties

Fuel Property	Industry Average	California Phase II – RFG
RVP* (psi)	8.7	6.8
T50 (°F)	218	200
T90 (°F)	330	290
Aromatics (vol %)	32	22
Olefins (vol %)	9.2	4
Benzene (vol %)	1.53	0.8
Sulfur (ppm)	339	30
Oxygen (wt %)	0	2

*RVP = Reid vapor pressure

Summary of Results

The data collected were analyzed to determine the cost of operating CNG vehicles compared to gasoline vehicles, and to assess the performance and reliability of the vehicles. The sections that follow present and discuss the study results in terms of vehicle use, fuel economy, maintenance experience, fleet operating cost, and emissions performance of the CNG vehicles in comparison to the gasoline study vehicles.

Operating Data Results

Vehicle Use

During the study period, the CNG study vehicles accumulated anywhere from 80,300 to 155,000 miles, averaging nearly 108,000 miles. The gasoline vehicles accumulated from 112,000 to 143,000 miles, averaging about 127,000 miles. Table 5 provides information on vehicle usage (through July 31, 1998).
In the course of the study, the CNG vehicles accumulated slightly less mileage (about 3% less) on a monthly basis than the gasoline vehicles—5,737 miles compared to 5,885 miles on average for the gasoline vehicles. Most of the gasoline vehicles were put into service between September and November of 1996. The CNG vehicles were put into service in late December 1996 and January 1997, except for one that went into service in April 1997. The gasoline study vehicles were in service 3 months longer, on average, than the CNG study vehicles.

There was essentially no difference in the use of the CNG vehicles in the Barwood fleet based on monthly vehicle mileage. Differences in mileage accumulation rate—vehicle to vehicle—are the result of the work patterns of individual drivers. The drivers are free to operate the vehicle as much or as little as they desire as long as they pay their vehicle rent and abide by their contract with Barwood.

The more limited availability of CNG (compared to gasoline) throughout the metro DC area did have some effect on where CNG vehicle drivers were willing to go to pick up or drop off fares. In addition, this version of the CNG Crown Victoria had reduced trunk space because the fuel tanks were installed in the trunk. Because of this, some CNG drivers had to pass up fares with large amounts of luggage. Based on this fleet's

Table 5. Vehicle Mileage Accumulation Data

Cab Number	Acquisition Date	End of Study Odometer	Months in Service	Average Miles Accumulated per Month
CNG Vehicles				
223	4/9/97	80,349	15.7	5,118
238	12/20/96	155,044	19.4	8,008
296	1/20/97	126,369	18.4	6,883
411	1/3/97	75,844	18.9	4,013
413	12/12/96	88,284	19.6	4,502
427	1/7/97	92,132	18.8	4,908
456	12/16/96	118,066	19.5	6,061
463	12/20/96	120,369	19.4	6,217
480	12/20/96	104,442	19.4	5,395
530	1/3/97	118,345	18.9	6,262
CNG Average		**107,924**	**18.8**	**5,737**
Gasoline Vehicles				
261	8/27/96	141,698	23.1	6,126
329	10/15/96	143,126	21.5	6,651
376	10/30/96	112,697	21.1	5,349
492	9/11/96	117,698	22.6	5,201
521	9/18/96	123,369	22.4	5,508
528	10/3/96	122,951	21.9	5,614
533	10/3/96	129,229	21.9	5,901
545	9/30/96	129,369	22	5,880
676	9/27/96	120,111	22.1	5,435
692	1/10/97	134,209	18.7	7,185
Gasoline Average		**127,446**	**21.7**	**5,885**

experience, it is estimated that typical CNG drivers would have to pass up less than 0.5% of the fares (over the course of a year) because of trunk space limitations.

Fuel Economy and Cost

Table 6 summarizes the fuel economy and fuel cost results. The data presented are the averages for each vehicle type, and were based on the fueling records from May 1998 through July 1998. During this time period, the gasoline vehicle drivers received a monetary incentive to collect and submit fueling records, and the gasoline fueling records were very complete for eight out of ten of the study vehicles. During the rest of the study period, the quality of the gasoline fueling records was mixed, and in many cases poor. All good records from the May through July period were included in the analysis. To ensure a direct comparison, the CNG results presented in Table 6 are also for only the May 1998 through July 1998 period. The CNG and gasoline fueling records for this period are summarized by vehicle in Appendix B.

The average fuel economies of the CNG and gasoline versions of this vehicle were nearly identical. One might expect these results because these vehicles are being operated in the same types of service, and the EPA-estimated fuel economy numbers for the two vehicles are the same (on an equivalent gallon of gasoline basis).

Table 6. Fuel Economy and Cost Summary*

Vehicle	Fuel Economy (average mpg)	Fuel Cost (cents per mile)
CNG Crown Victoria	17.30	4.35
Gasoline Crown Victoria	17.31	6.39

*on an equivalent gallon of gasoline basis

The fuel cost for CNG, on a cent per mile basis, was more than 30% lower than gasoline, at 4.35 cents per mile compared to gasoline's 6.39 cents per mile. Over the course of the study the cost of CNG ranged from $0.70 to $0.84 per gasoline gallon equivalent (GGE). During the May through July period, CNG cost between $0.74 and $0.76 per GGE, and averaged $0.75 per GGE. The drivers reported paying gasoline prices that ranged anywhere from a low of about $0.90 per gallon to a high of $1.38 per gallon. During the May through July time period, the price of gasoline averaged $1.10 per gallon.

Maintenance Data and Cost

Maintenance and repair records, including cost data, were collected throughout the study period. In addition, Barwood provided all available records back to when the study vehicles went into service. As described previously, Barwood runs a full-service vehicle maintenance facility. The maintenance facility staff is tasked with checking, servicing, and repairing all of Barwood's fleet vehicles.

The manufacturer recommends that these vehicles receive scheduled maintenance (such as oil changes and fluid checks) every 5,000 miles. Barwood exceeds this standard, by requiring its drivers to bring in their vehicles for "regular scheduled maintenance" at 4,000-mile intervals. Barwood's scheduled maintenance included:

- Oil and filter change
- Fluid checks (such as washer and brake, as well as checking for leaks) and inspect wipers
- Brake and brake assembly checks
- Tire inspection
- Test drive to check handling/maneuvering
- Belt and hose inspections
- Noise check (such as rattles)
- Condition of interior and exterior of vehicle (such as scratches, dents, and condition of seats)
- Two-way communications system resetting
- Fare-registering device check
- Condition of advertisements on cab.

Also, depending on the mileage accumulated on the vehicle, the scheduled maintenance would include:

- Spark plug and wire inspection (and possibly replacement)
- Electrical system (including new batteries if needed)
- Tune-up
- Engine cooling systems (such as radiator)
- Drive train inspection (transmission)
- Fuel distribution system (fuel filter and injectors)
- Suspension system inspection.

Barwood takes a proactive approach to maintaining its vehicles, with a focus on preventing problems so the vehicles can be on the road as much as possible. Repairs required that were beyond those listed above (or those required at times different from the manufacturer's recommended intervals) were defined as unscheduled maintenance.

Table 7 summarizes the number and timing of the maintenance for the study vehicles. The number of service visits was higher for the gasoline vehicles (291 compared to 248 for the CNG vehicles). This is to be expected because the gasoline vehicles were in service an average of 3 months longer than the CNG vehicles. The number of miles and days between service visits is nearly the same for the two vehicle types, which indicates that there is no difference in the care given to the CNG vehicles compared to the gasoline vehicles.

Table 7. Summary of Number and Frequency of Maintenance Checks

Data	CNG Vehicles	Gasoline Vehicles
Number of months in service (all study vehicles)	187.8	217.3
Total accumulated mileage (all study vehicles)	1,083,317	1,271,730
Number of scheduled maintenance services	181	206
Number of unscheduled maintenance repairs	67	85
Total number of maintenance visits (scheduled and unscheduled)	248	291
Average numbers of miles between servicing	4,368	4,370
Average frequency of scheduled maintenance	31.1 days	31.6 days

The maintenance and repair records and cost data were grouped into scheduled, unscheduled, non-mechanical repairs, and other categories. The scheduled maintenance category was described above. The unscheduled maintenance or repairs included all non-scheduled repairs, including those resulting from problems reported by the vehicle drivers, vehicle breakdowns, and repairs resulting from accidents. Non-mechanical repairs typically included work and costs associated with changing advertising on the vehicles, checking the radio, resetting the fare meter, installing new carpeting, and cleaning or touching up the vehicle. The other category included costs such as towing, and any other items that did not fit in the previous categories.

The scheduled and unscheduled maintenance records were reviewed by vehicle type (CNG and gasoline) to evaluate whether any repairs occurred more frequently on either type of vehicle. We looked for frequencies of items such as brake work, tire replacement, fuel system repairs, or engine-related repairs.

As reported above, there was no difference in the frequency of scheduled maintenance, and the vehicles followed the same service schedule. The rate of unscheduled repairs was slightly higher for the gasoline

This project has shown that the dedicated CNG Crown Victoria sedan compares well with the gasoline-only version.

vehicles than the CNG vehicles (on a per mile basis). No differences in the types or frequencies of fuel system or engine-related maintenance and repairs were discovered between the CNG and gasoline vehicles. When compared over similar mileage ranges, the gasoline vehicles tended to need slightly more repairs related to brakes and tires than did the CNG vehicles. The cause of this difference is not entirely clear, but the drivers of the CNG cabs indicated that their vehicles do not accelerate as quickly as gasoline vehicles. These drivers indicated that the vehicle responsiveness forced them to modify how they drive these vehicles (reduced “jack-rabbit” starts, for example). It is possible that this affected both brake and tire wear in the CNG vehicles.

Recall repairs were required on six of the CNG and six of the gasoline vehicles. None of the recalls were for fuel-related repairs, and all were completed at no cost to the cab company. Five of the CNG and seven of the gasoline vehicles were involved in accidents that resulted in a number of unscheduled repairs. Nearly all the accident repairs involved bodywork, and none involved any fuel- or engine-related repairs. One CNG vehicle accident was a fairly major rear-end collision. The fleet was very pleased that the integrity of the CNG fuel system (fuel tanks and lines) was maintained—no leaks or other problems occurred in the CNG systems.

Overall, minor differences were seen in the maintenance and repair histories for the CNG and gasoline Crown Victoria. Based on the maintenance and repair data, the fleet experienced similar performance and reliability for the two vehicle types.

Table 8 summarizes the maintenance and repair costs (a summary of cost information by vehicle is provided in Table B-3 in Appendix B). The unscheduled maintenance and total maintenance costs are reported with and without the accident repair costs. The costs without accidents better represent the actual unscheduled maintenance because both the rate and severity of accidents will vary from fleet to fleet. Overall, total maintenance costs (without accidents) were lower for the CNG vehicles. Maintenance and repair costs were 3.39 cents per mile for the CNG vehicles compared to 3.95 cent per mile for the gasoline vehicles. Barwood’s experience during the study period, then, was that the CNG vehicles cost about 15% less to maintain than the gasoline vehicles.

Table 8. Maintenance and Repair Cost Summary

	CNG Vehicles	Gasoline Vehicles
Scheduled maintenance (average for vehicle type)	$2,354	$3,454
Unscheduled maintenance (average—with accidents)	$1,628	$1,499
Unscheduled maintenance (average—without accidents)	$519	$769
Non-mechanical repairs (average for vehicle type)	$711	$634
Other costs (average for vehicle type)	$46	$123
Total maintenance and repair (average—without accidents)	$3,630	$4,979
Total maintenance and repair: cents per mile (average—without accidents)	3.39	3.95

Total Operating Costs

By combining the fueling and maintenance cost results, we arrive at the summary of operating costs shown in Table 9. During the course of this study, the CNG vehicles cost about 25% less than the gasoline vehicles on a per mile basis to fuel and maintain. Based on these operating costs, a fleet could expect to save about $1,300 a year in costs for a CNG vehicle accumulating 50,000 miles per year. For a vehicle accumulating 15,000 miles annually (more typical mileage for light-duty vehicles), cost savings of about $390 would be realized.

The incremental cost difference between the CNG and gasoline Crown Victoria was approximately $3,000 (after accounting for the manufacturer's rebate) in 1998. In a high mileage application like Barwood's cab fleet, the payback period for the incremental cost would be less than 2 1/2 years. Many fleets are also eligible for federal and state tax incentives, which can further reduce the incremental cost difference and the resulting payback period. For instance, in Maryland (where Barwood is located) a fleet could be eligible for federal and state incentives of about $1,300, which would reduce the incremental cost difference on the CNG Crown Victoria to about $1,700. Again, for a fleet with costs and mileage similar to those of Barwood, the payback period would be only about 1.3 years, and beyond that period the fleet would reduce its costs by operating the CNG vehicles.

It is worthwhile to note that Barwood does not realize all the possible savings for operating the CNG vehicles. Because their vehicle drivers pay for their own fuel, much of the total operating cost savings goes to the

Table 9. Total Operating Cost Summary

	CNG Vehicles	Gasoline Vehicles
Average fuel usage cost (cents per mile)	4.35	6.39
Average maintenance cost (cents per mile)	3.39	3.95
Total operating costs (cents per mile)	7.7	10.3

drivers in reduced fuel costs. In this scenario, it is not likely that the fleet operator will break even on the incremental cost difference of the vehicles. However, in Barwood's case, the CNG vehicles cost essentially the same as the gasoline vehicles, because the Washington Gas Company provided funds to pay the incremental cost difference between the CNG and gasoline versions of the Crown Victoria.

Emissions Results

This section gives a detailed explanation of the emissions test results broken down into three subsections:

- Regulated emissions (nonmethane hydrocarbons [NMHC], total hydrocarbons [THC], carbon monoxide [CO], oxides of nitrogen [NO_x], and evaporative hydrocarbons [HC])
- Non-regulated emissions (formaldehyde [HCHO], acetaldehyde [CH_3CHO], carbon dioxide [CO_2], and methane [CH_4])
- Chassis dynamometer fuel economy.

Details on the average results are discussed and presented in Tables 10 and 11 and Figures 3 and 4. The tables show the average results for each emission constituent by fuel and test round. They also give the percent difference between the average CNG and RFG test results calculated as:

$$\text{Percent Difference} = \frac{\left(\overline{x}_{CNG} - \overline{x}_{RFG}\right)}{\overline{x}_{RFG}}$$

where $\overline{x}_{CNG}$ is the average CNG test result and $\overline{x}_{RFG}$ is the average RFG test result for a given emission constituent. Note that positive percentages indicate that the CNG test results were higher than the RFG result.

The tables also provide information on the results of the ANOVA in the columns labeled "significance test." In these columns, a "y" indicates that the factor in question had a significant effect on the results at the 95% confidence level. The factors discussed include fuels, rounds, and fuel x round (fuel by round) interactions. A "y" in the fuel column indicates a significant difference in the average emissions between fuels—independent of the other factors. Similarly, a "y" in the round or "fuel x round" columns indicates a significant difference resulting from these factors independent of the others. An example of a significant difference in emissions caused by the "fuel x round" interaction would be if the results from one fuel increased from one round to another, while the results for the other fuel decreased or stayed the same.

The graphs provide similar information in a visual format. Each graph shows the average results for a given fuel and test round, the EPA Tier 1 and ultra low emission vehicle (ULEV) emissions standards where applicable, and standard error bars. The gasoline vehicles were certified to EPA's Tier 1 standards; the CNG vehicles were certified to the more stringent ULEV standards. NMHC, NO_x, and CO emissions standards include an intermediate useful life standard applied at 50,000 miles and a less stringent full useful life standard applied at 100,000 miles. The gap between the Tier 1 and ULEV standards (see Figure 3) shows the increased stringency in the standards; the gap between the 50,000- and 100,000-mile standards shows the allowable emissions deterioration over the specified mileage levels. THC are regulated only for gasoline vehicles certified to Tier 1 at 50,000 miles. A standard is not shown for evaporative hydrocarbons because the regulations are written for a new, enhanced evaporative test procedure. The enhanced evaporative test was not included in this study because of cost considerations. Under previous EPA regulations (Tier 0), the THC had to remain below 2 g for the two 1-hour tests (cold soak + hot soak) conducted here. HCHO emissions are only regulated under the ULEV standards. The error bars were calculated as part of the ANOVA and can be used to visually assess whether differences in the average emissions between rounds or between fuels are statistically significant at the 95% confidence level.

Tables A-1 and A-2 in the appendix provide the detailed emissions data from each vehicle.

Regulated Emissions

Table 10 and Figure 3 show the average regulated emissions results. All the average regulated exhaust emissions results fell within the applicable EPA emissions standards (i.e., ULEV for the CNG vehicles, Tier 1 for the gasoline vehicles). The CNG vehicles had significantly lower levels of NMHC (approximately 66% lower), similar NO_x levels, and significantly higher THC (approximately 200% to 300% higher) emissions compared to the gasoline vehicles. Exhaust THC is a regulated pollutant for gasoline vehicles, but not for CNG, because most (in the range of 80% to 90% depending on the fuel composition) of the unburned hydrocarbons from natural gas vehicles consist of methane. Methane is not a regulated exhaust pollutant, because it is considered to be highly non-reactive in forming ozone in the atmosphere. Although there was not a statistically significant difference between the average NO_x results from the CNG and gasoline vehicles, the average NO_x emissions were quite low—hovering around the ULEV standards even though the gasoline vehicles were certified to less stringent Tier 1 standards (see Figure 3).

As shown in Table 10, there were significant differences in NMHC, THC, and CO emissions from one round to another. However, when the results are separated by fuel type, the increases in average regulated exhaust emissions (NMHC, CO, and NO_x) from one round to another were not statistically significant for the CNG vehicles. For the gasoline vehicles, statistically significant increases were observed for NMHC (between Rounds 1 and 2), CO (between Rounds 1 and 2, and between Rounds 2 and 3), and NO_x (between Rounds 2 and 3). Additionally, the rate of deterioration of CO and NMHC emissions from Round 1 to Round 3 tended to be higher for the gasoline vehicles than for the CNG vehicles. However, the correlation between emissions rate and odometer also tended to be very weak, with r^2 values ranging from approximately 0.1 to 0.3. The rates of deterioration for NO_x emissions were nearly identical for both the CNG and gasoline vehicles.

CNG vehicles do not have "evaporative" emissions per se, because the fuel is a high-pressure gas maintained in a closed fuel system. For that reason, dedicated CNG vehicles like the Crown Victoria do not incorporate separate evaporative emission control systems. This allows these vehicles to qualify under the EPA's inherently

Table 10. Average Results for Regulated Emissions

	Test Round (thousands of miles)	Average Results		Percent Difference	Significance Test		
		CNG	RFG		Fuel	Round	Fuel x Round
Regulated Exhaust Emissions (g/mi)							
NMHC	60	0.049	0.125	-61.1%	y	y	y
	90	0.055	0.172	-67.8%			
	120	0.045	0.177	-74.7%			
THC	60	0.603	0.146	313%	y	y	n
	90	0.632	0.199	218%			
	120	0.761	0.209	264%			
CO	60	0.928	2.764	-66.4%	y	y	n
	90	1.257	3.703	-66.1%			
	120	2.043	4.622	-55.8%			
NO_x	60	0.243	0.263	-7.5%	n	y	n
	90	0.295	0.269	9.7%			
	120	0.309	0.338	-8.6%			
Evaporative Emissions (g)							
Cold Soak	60	0.089	0.030	194%	y	n	n
	90	0.117	0.035	234%			
	120	0.075	0.044	71.8%			
Hot Soak	60	0.209	0.031	582%	y	n	n
	90	0.246	0.044	463%			
	120	0.212	0.040	436%			
Total	60	0.298	0.061	390%	y	n	n
	90	0.363	0.079	361%			
	120	0.287	0.104	175%			

low emission vehicle (ILEV) standards. However, in the modified 1-hour evaporative tests performed before (cold soak) and after (hot soak) the exhaust tests, the CNG vehicles did emit low levels of hydrocarbons. The average results were significantly higher than the evaporative HCs from the gasoline vehicles, which had extremely low (less than 0.1 g) total evaporative emissions during the 1-hour tests. It should be noted that hydrocarbons emanating from CNG vehicles are primarily methane; HCs evaporating from gasoline vehicles are made up of more reactive and toxic hydrocarbon species. In general, the differences in average

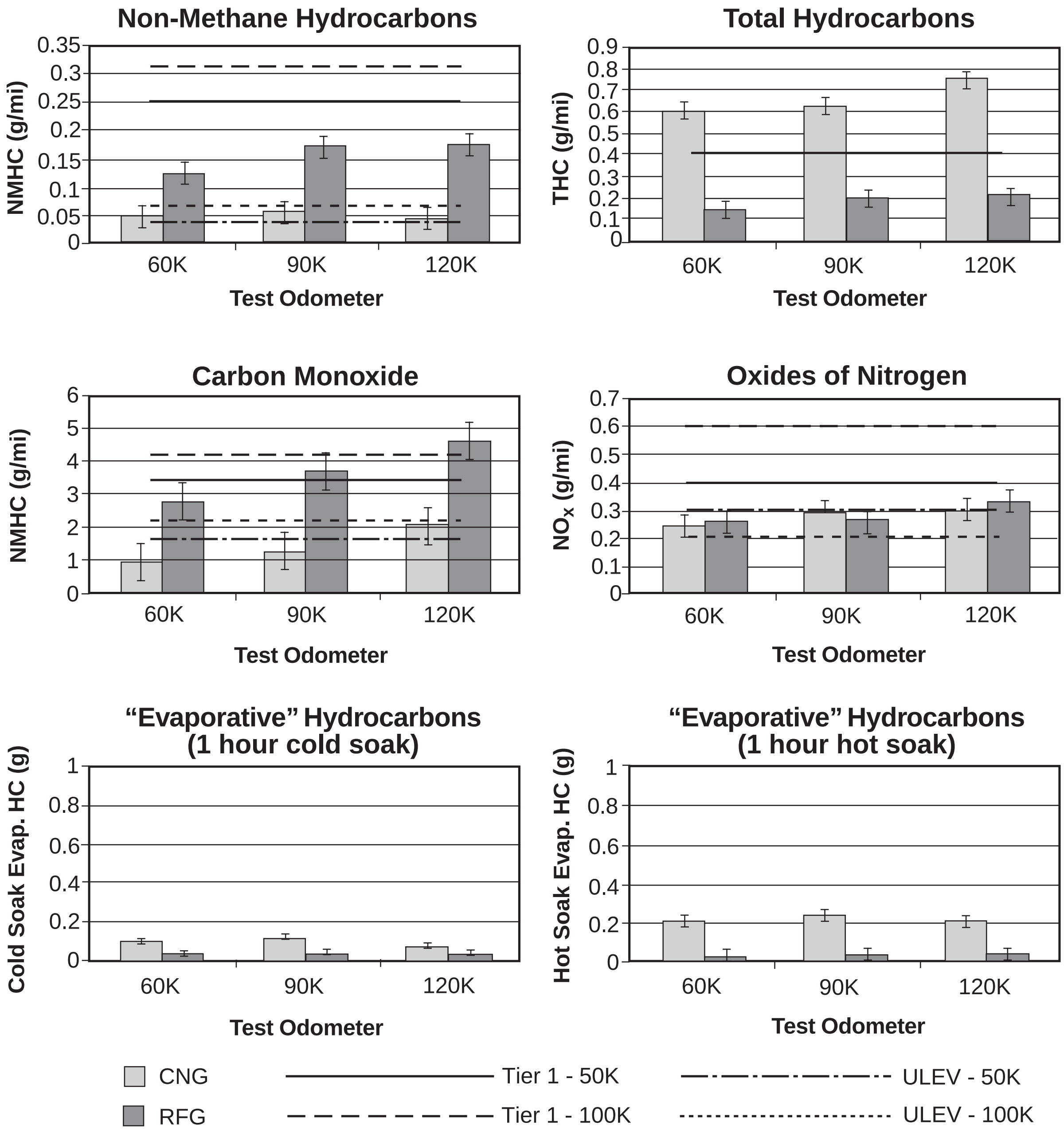

Figure 3. Average regulated emissions test results from the study vehicles

Non-Regulated Emissions Results

The non-regulated emissions that were measured and evaluated include HCHO, CH_3CHO, CO_2, and CH_4. HCHO is included as a regulated emissions constituent under the ULEV standards, but not under the Tier 1 standards. Table 11 and Figure 4 present the average results of these emissions constituents.

Table 11. Average Results for Non-Regulated Emissions and Fuel Economy

	Test Round (thousands of miles)	Average Results		Percent Difference	Significance Test		
		CNG	RFG		Fuel	Round	Fuel x Round
Aldehyde Emissions (g/mi)							
HCHO	60	0.0043	0.0036	17.6%	n	n	n
	90	0.0045	0.0041	9.9%			
	120	0.0037	0.0039	-4.8%			
CH_3CHO	60	0.00020	0.00047	-58.2%	y	y	y
	90	0.00022	0.00066	-66.3%			
	120	0.00021	0.00071	-67.6%			
Greenhouse Gas Emissions (g/mi)							
CO_2	60	411.5	492.6	-16.5%	y	n	n
	90	415.4	487.4	-14.8%			
	120	409.5	485.9	-15.7%			
CH_4	60	0.555	0.026	1980%	y	y	y
	90	0.581	0.034	1620%			
	120	0.725	0.041	1680%			
Fuel Economy* (mpg)							
MPG	60	15.9	17.8	-10.7%	y	n	n
	90	15.7	17.9	-12.5%			
	120	15.9	17.9	-11.5%			

*on a mile per equivalent gallon of gasoline basis for CNG

The differences in average HCHO emissions from the CNG and RFG tests were not statistically significant, but the levels from both were well below the ULEV standard of 0.008 g/mi. The average CH_3CHO and CO_2 levels were significantly lower from the CNG vehicles compared to the gasoline vehicles tested on RFG. The average CH_3CHO emissions from both vehicle types were very low (less than 0.0008 g/mi). The CNG vehicle CH_3CHO emissions were between 58% and 71% lower than the RFG results. The CO_2 emissions from the CNG vehicles were between 15% and 18% lower than the RFG results. CH_4 emissions from the CNG vehicles were much higher than those from the gasoline vehicles, as expected.

In comparing the average non-regulated exhaust emissions between test rounds, there was no statistically significant difference in CO_2 or HCHO emissions from one test round to another. There was a significant increase in CH_3CHO emissions from the gasoline vehicles between Round 1 and Round 2, but the change from Round 2 to Round 3 was not significant. For CNG, the difference in average CH_3CHO emissions between rounds was not statistically significant.

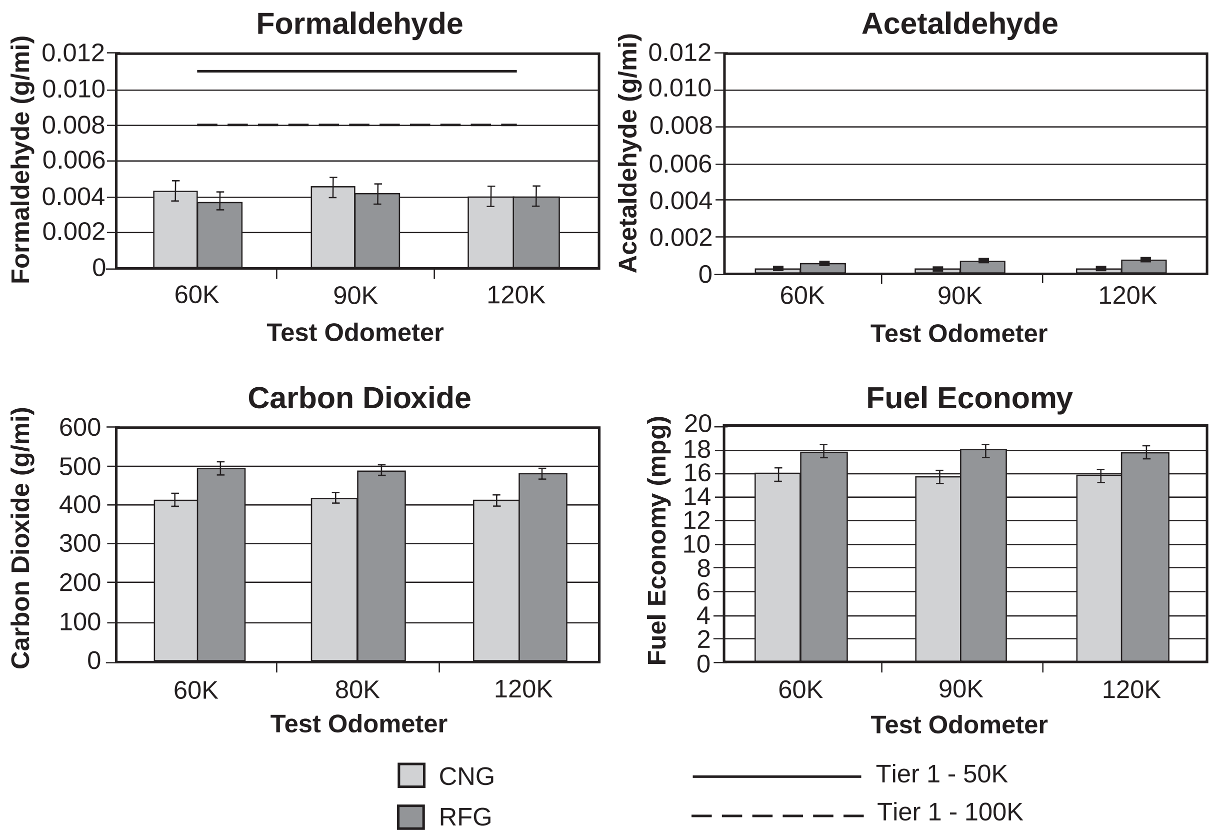

Figure 4. Average non-regulated emissions and fuel economy results from the study vehicles

Fuel Economy

The EPA FTP-75 includes an urban fuel economy estimate that is derived from the results of the chassis dynamometer test procedure. As shown in Table 11, the estimated urban fuel economy was between 9.6% and 12.5% lower from the CNG vehicles compared to the gasoline vehicles tested on RFG. The average CNG fuel economy of 15.8 mpg and 15.9 mpg was approximately 7% below the EPA estimated city fuel economy of 17 mpg. The average RFG fuel economy of 17.7 mpg was approximately 4% above the EPA estimate.

As an additional measure of the fuel economy performance of the two vehicle types, the EPA's highway fuel economy test (HWFET) was performed on three of the CNG vehicles and five of the gasoline vehicles during the third round of testing (i.e., at an odometer reading of approximately 120,000). For the HWFET, the average highway fuel economy estimate for CNG was 29.4 mpg and for RFG it was 31.3. The CNG highway fuel economy was approximately 5.6% lower than the average from the RFG tests. The statistical validity of this result was not determined because of the limited sample size. The values measured by this program were between 17% (CNG) and 25% (RFG) higher than the highway fuel economy estimate of 25 mpg published by the EPA.

The fuel economy measured on the dynamometer was somewhat different than that from the real world refueling records, where the CNG and gasoline fuel economy (17.3) was slightly higher than the EPA city-driving estimate. It is actually rather difficult to make a direct comparison between the measured and real world fuel economy. The vehicles in this fleet operate in mixed driving cycles, which typically includes about

Based on this study, the CNG vehicles offer advantages in terms of fleet economics and reduced environmental impact.

two-thirds city driving and one-third highway driving, and actual fuel economy results are also affected by individual driving style.

Conclusion

Results from this project show that the dedicated CNG Crown Victoria sedan compares well with the gasoline-only version. The CNG vehicles are generally being operated in the same service as the gasoline-only vehicles, and receive servicing on the same schedule. The CNG vehicles are accumulating nearly the same amount of miles on a monthly basis as the gasoline vehicles. A fuel economy of 17.3 miles per gallon (equivalent gallons of gasoline basis for CNG) was achieved for both vehicle types during the period considered. The resulting fuel usage costs were about 30% lower for CNG (4.35 cents per mile) than gasoline (6.39 cents per mile).

The maintenance and repair records did not reveal any big differences in the maintenance histories of these vehicles, although the gasoline vehicles did have more occurrences of brake- and tire-related repairs. No differences in the types or frequencies of fuel system or engine-related repairs were uncovered. The fleet indicated that the CNG vehicles perform as well as, and are as reliable as, the gasoline version of the vehicle. In terms of costs, the CNG vehicles were found to have total maintenance and repair costs (excluding costs associated with accidents) somewhat lower than the gasoline vehicles (3.39 cents per mile compared to 3.95 for the gasoline vehicles).

The total operating costs of the CNG vehicles were about 25% lower than were those of the gasoline vehicles (7.7 cents per mile compared to 10.3 for the gasoline vehicles). Cost differences such as these could result in costs savings to a fleet—particularly in a high mileage application such as the cab fleet evaluated here. Most of the cost advantages associated with operating these CNG vehicles result from fuel price differences. The study fleet does not enjoy most of the cost benefits, because of the way the fleet is operated, with the drivers paying for the fuel rather than the fleet.

In general, the results of the emissions testing confirm some of what is already accepted about well-designed dedicated CNG vehicles. Namely, CNG exhaust emissions tend to be significantly lower than their gasoline counterparts—even when using a very clean reformulated gasoline as the baseline. However, this study is one of the first to provide an independent confirmation that these benefits can be maintained in real-world service throughout the useful life (100,000 miles) of the vehicle and beyond. Although the results are not conclusive, they tend to suggest that emissions from CNG vehicles may, in fact, deteriorate less quickly than those from similar gasoline vehicles. Additional testing and more in-depth analysis is needed to quantify this result, but this may add some fuel to the drive for establishing separate deterioration factors for CNG and gasoline vehicles that are used in the EPA inventory models.

It should be noted that while general trends between fuels are likely to hold true, the level of benefit achieved for the various emissions constituents depends strongly on factors such as engine design, calibration, and emissions targets for the vehicles being compared. For instance, the specific differences in emissions of CO, NMHC, and NO_x for the gasoline and CNG Crown Victoria, while similar in trend, may be quite different from those seen in a comparison of a CNG and gasoline Honda Civic, or for that matter, updated versions of the Crown Victoria.

Another interesting result is that the hydrocarbons emitted from the CNG vehicle during the modified evaporative procedure, while low, were not zero and were even higher than those emitted from the gasoline vehicles. To some this may be a moot point since the hydrocarbons released are primarily non-reactive methane. On the other hand, the current evaporative emissions standards regulate total hydrocarbons as opposed to non-methane hydrocarbons. From this data (as well as from other tests performed by NREL), it seems that claims of zero "evaporative" emissions from dedicated CNG vehicles seem to be exaggerated. It also seems that a non-methane hydrocarbon standard for evaporative emissions from CNG vehicles would be more consistent with the exhaust emissions standards and would support claims of near-zero evaporative emissions from CNG vehicles.

Based on this study, the CNG vehicles operated by this fleet provide advantages—both in terms of fleet economics and of reduced environmental impact. Barwood found the performance and reliability of the CNG vehicles to be comparable or better than that of their gasoline vehicles. The drivers and maintenance staff no longer have concerns about operating or working on the CNG vehicles. The fleet's drivers who have operated the CNG vehicles no longer look at them as "something different," but consider the CNG vehicles "just like any other vehicle." Barwood and its' drivers have come to consider the CNG vehicles an asset to their business, and to the air quality of their community.

Acknowledgments

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Appendix A:

Detailed Emissions Test Results for Each Vehicle

Table A-1. CNG Test Results
(Repeats Averaged with Outliers Shaded)

Cab No.	Test Date	Test Odometer	Test Fuel	MPG	Exhaust Emissions (g/mi)									Evaporative HCs (g)		
					CH_3CHO	CH_4	CO	CO_2	HCHO	NMHC	NO_x	THC	Carbonyls	Soak	Soak	Total
238	8/13/97	63026	CNG	16.4	0.00024	0.474	0.884	397.2	0.0048	0.031	0.245	0.504	0.0058	0.099	0.210	0.309
238	12/9/97	92413	CNG	15.7	0.00036	0.577	2.410	413.0	0.0038	0.071	0.257	0.648	0.0043	0.081	0.308	0.389
238	3/25/98	119288	CNG	15.2	0.00025	0.699	3.189	426.1	0.0048	0.040	0.354	0.736	0.0055	0.065	0.236	0.301
296	10/22/97	59130	CNG	15.7	0.00010	0.479	0.802	418.5	0.0046	0.044	0.203	0.523	0.0048	0.169	0.231	0.400
296	2/10/98	90840	CNG	15.7	0.00024	0.502	1.214	414.5	0.0039	0.029	0.194	0.529	0.0045	0.127	0.380	0.507
296	5/14/98	115839	CNG	15.9	0.00017	0.685	1.660	409.6	0.0042	0.026	0.265	0.708	0.0051	0.063	0.243	0.306
413	11/18/97	56924	CNG	15.1	0.00018	0.890	1.228	431.2	0.0066	0.049	0.379	0.936	0.0072	0.070	0.203	0.274
413	7/30/98	88307	CNG	15.7	0.00038	1.561	1.182	413.8	0.0051	0.078	0.392	1.632	0.0056	0.167	0.323	0.490
413	2/4/99	115433	CNG	15.9	0.00039	1.502	3.186	405.8	0.0034	0.080	0.351	1.576	0.0042	0.063	0.266	0.328
456	10/1/97	59421	CNG	15.6	0.00026	0.605	0.810	418.3	0.0042	0.060	0.272	0.665	0.0054	0.069	0.185	0.254
456	3/11/98	89521	CNG	15.5	0.00012	0.945	0.870	420.9	0.0045	0.077	0.368	1.020	0.0050	0.093	0.209	0.302
456	8/20/98	122000	CNG	16.2	0.00029	1.052	1.626	400.0	0.0037	0.042	0.351	1.090	0.0049	0.090	0.251	0.341
463	8/21/97	62907	CNG	15.9	0.00028	0.566	1.348	410.4	0.0035	0.051	0.144	0.616	0.0046	0.075	0.279	0.353
463	11/25/97	95738	CNG	15.9	0.00025	0.413	1.235	410.4	0.0049	0.054	0.287	0.468	0.0057	0.074	0.154	0.229
463	5/12/98	116564	CNG	15.5	0.00014	0.498	1.474	420.2	0.0041	0.037	0.226	0.534	0.0044	0.063	0.218	0.281
480	10/2/97	58664	CNG	16.3	0.00012	0.469	0.788	401.4	0.0027	0.060	0.263	0.529	0.0032	0.089	0.235	0.324
480	3/12/98	89597	CNG	15.7	0.00020	0.529	0.924	415.8	0.0035	0.036	0.264	0.564	0.0040	0.152	0.231	0.382
480	12/17/98	122156	CNG	16.3	0.00016	0.802	1.628	398.3	0.0030	0.048	0.265	0.847	0.0037	0.085	0.144	0.230
530	9/25/97	60246	CNG	16.3	0.00019	0.405	0.633	403.5	0.0036	0.045	0.198	0.450	0.0047	0.050	0.123	0.172
530	2/12/98	88305	CNG	15.6	0.00012	0.521	0.962	419.7	0.0060	0.041	0.303	0.561	0.0066	0.124	0.116	0.240
530	9/3/98	124214	CNG	16.1	0.00020	1.611	1.536	406.4	0.0030	0.041	0.352	0.651	0.0038	0.098	0.125	0.223
			Count	21	21	21	21	21	21	21	21	21	21	21	21	21
			Average	15.8	0.00022	0.704	1.409	412.10	0.0042	0.049	0.283	0.752	0.0049	0.094	0.222	0.316
			Std Dev	0.4	0.00008	0.326	0.720	9.20	0.0010	0.016	0.069	0.334	0.0010	0.035	0.068	0.085
			Max	16.4	0.00039	1.561	3.189	431.24	0.0066	0.080	0.392	1.632	0.0072	0.169	0.380	0.507
			Min	15.1	0.00010	0.405	0.633	397.21	0.0027	0.026	0.144	0.450	0.0032	0.050	0.116	0.172

Table A-2. RFG Test Results
(Repeats Averaged with Outliers Shaded)

Cab No.	Test Date	Test Odometer	Test Fuel	MPG	Exhaust Emissions (g/mi)									Evaporative HCs (g)		
					CH_3CHO	CH_4	CO	CO_2	HCHO	NMHC	NO_x	THC	Carbonyls	Soak	Soak	Total
261	7/31/97	64433	RFG	17.6	0.00051	0.025	2.60	498.9	0.0025	0.116	0.192	0.136	0.0048	0.034	0.036	0.070
261	11/20/97	90844	RFG	17.9	0.00080	0.041	4.02	489.1	0.0046	0.176	0.279	0.209	0.0082	0.044	0.033	0.077
261	4/8/98	118199	RFG	17.7	0.00075	0.051	6.11	490.5	0.0048	0.223	0.361	0.264	0.0081	0.017	0.046	0.063
376	8/29/97	57994	RFG	17.8	0.00042	0.036	4.08	491.7	0.0029	0.134	0.260	0.162	0.0045	0.030	0.030	0.060
376	3/18/98	88297	RFG	18.0	0.00056	0.040	4.95	484.4	0.0040	0.168	0.271	0.200	0.0069	0.043	0.054	0.097
376	9/17/98	119517	RFG	16.2	0.00060	0.044	5.21	535.5	0.0033	0.131	0.353	0.165	0.0067	0.063	0.106	0.160
521	8/27/97	62255	RFG	17.8	0.00036	0.029	3.16	493.0	0.0044	0.146	0.215	0.169	0.0061	0.033	0.020	0.053
521	1/21/98	91755	RFG	17.7	0.00081	0.029	2.64	496.3	0.0046	0.169	0.328	0.192	0.0078	0.026	0.046	0.072
521	7/2/98	123254	RFG	16.3	0.00071	0.037	4.74	536.8	0.0040	0.133	0.348	0.162	0.0064	0.058	0.097	0.164
528	8/14/97	59415	RFG	18.0	0.00041	0.019	1.34	490.3	0.0035	0.106	0.251	0.121	0.0059	0.026	0.033	0.059
528	1/28/98	87471	RFG	18.0	0.00069	0.033	3.79	484.1	0.0085	0.185	0.128	0.211	0.0101	0.037	0.049	0.086
528	7/22/98	115097	RFG	18.1	0.00066	0.039	4.67	479.9	0.0042	0.196	0.203	0.227	0.0075	0.045	0.039	0.084
533	8/8/97	63123	RFG	18.2	0.00057	0.035	3.58	481.1	0.0041	0.143	0.415	0.171	0.0065	0.028	0.022	0.051
533	1/8/98	93869	RFG	18.0	0.00077	0.031	2.70	486.0	0.0112	0.175	0.393	0.200	0.0112	0.040	0.032	0.072
533	7/15/98	126500	RFG	17.7	0.00072	0.028	2.30	495.5	0.0034	0.147	0.384	0.170	0.0071	0.055	0.032	0.087
545	8/7/97	65909	RFG	17.7	0.00051	0.023	3.04	494.5	0.0042	0.121	0.237	0.139	0.0065	0.047	0.044	0.091
545	12/23/97	93234	RFG	18.0	0.00058	0.043	5.51	481.6	0.0038	0.178	0.319	0.213	0.0060	3.253	0.143	3.396
545	6/24/98	123865	RFG	17.9	0.00103	0.050	5.79	485.2	0.0043	0.257	0.468	0.297	0.0092	4.533	1.128	5.661
692	8/20/97	61428	RFG	17.7	0.00049	0.020	1.54	498.7	0.0039	0.109	0.272	0.125	0.0059	0.013	0.030	0.042
692	1/14/98	93694	RFG	17.9	0.00044	0.020	2.31	490.6	0.0036	0.151	0.165	0.167	0.0055	0.020	0.048	0.068
692	4/29/98	117361	RFG	18.3	0.00047	0.036	3.54	478.5	0.0035	0.150	0.250	0.179	0.0055	0.027	0.041	0.068
		Count	21	21	21	21	21	21	21	21	21	21	21	21	21	
		Average	17.7	0.00061	0.034	3.70	493.4	0.0044	0.158	0.290	0.185	0.0070	0.403	0.100	0.504	
		Std Dev	0.5	0.00017	0.009	1.37	15.4	0.0019	0.038	0.088	0.043	0.0017	1.178	0.237	1.385	
		Max	18.3	0.00103	0.051	6.11	536.8	0.0112	0.257	0.468	0.297	0.0112	4.533	1.128	5.661	
		Min	16.2	0.00036	0.019	1.34	478.5	0.0025	0.106	0.128	0.121	0.0045	0.013	0.020	0.042	

Barwood CNG Cab Fleet:

Appendix B:

Fueling and Maintenance Data and Cost Summary by Vehicle

Barwood CNG Cab Fleet:

Tables B-1 and B-2 summarize the fuel use and cost summary information for each study vehicles. The summary includes all fuel use data available for the months of May, June, and July 1998. Table B-3 summarizes the maintenance and repair cost data by vehicle.

Table B-1. CNG Vehicles: Fuel Use and Cost Data Summary by Vehicle

Cab Number	Monthly Fuel Costs	Gallons* used per month	Miles traveled (5/1-7/31/98)	Cents/Mile	Miles per gallon*	Average $/gge*
223	$530.15	708.1	13244	4.00	18.70	$0.75
238	$997.01	1333.51	23088	4.32	17.31	$0.75
296	$1,161.98	1553.1	25987	4.47	16.73	$0.75
411	$428.66	569.64	11177	3.84	19.62	$0.75
413	$552.78	739	11936	4.63	16.15	$0.75
427	$182.28	243.8	4015	4.54	16.47	$0.75
456	$846.84	1131.1	18594	4.55	16.44	$0.75
463	$170.22	229.1	4365	3.90	19.05	$0.74
480	$514.09	688.7	10476	4.91	15.21	$0.75
530	$678.77	906.6	15673	4.33	17.29	$0.75
Average	$606.28	810.27	13865	4.35	17.30	$0.75

*on gasoline gallon equivalent (gge) basis

Table B-2. Gasoline Vehicles: Fuel Use and Cost Data Summary by Vehicle

Cab Number	Monthly Fuel Costs	Gallons used per month	Miles traveled (5/1-7/31/98)	Cents/Mile	Miles per gallon	Average $/gge
261	$779.62	717.6	12193	6.42	16.99	$1.086
329	$936.26	904.9	16949	5.52	18.73	$1.035
376	$956.00	820.4	13395	7.12	16.33	$1.165
492	$522.40	458.2	8791	5.90	19.19	$1.140
521	$800.62	738.4	10942	7.34	14.82	$1.084
528	$856.23	774.1	13527	6.35	17.47	$1.106
533	$214.51	200.4	2929	7.32	14.62	$1.071
545	$991.24	851.5	15332	6.46	18.01	$1.164
676	$79.00	75.0	1493	5.29	19.91	$1.053
692	$576.06	546.4	9291	6.17	17.00	$1.054
Average	$671.19	608.69	10484.2	6.39	17.31	$1.10

Table B-3. Summary of Maintenance and Repair Cost Data by Vehicle for Each Fuel

Cab Number	Odometer	Scheduled Maint-enance	Accident costs	Unscheduled Maintenance (w/o accidents)	Non-mechanical repairs	Other charges	Total M&R cost	Total (without accidents)	Cents/mile (with accidents)	Cents/mile (without accidents)
CNG Vehicles										
223	82090	$1,647.14	$0.00	$171.00	$57.20	$57.00	$1,932.34	$1,932.34	2.35	2.35
238	154581	$3,147.31	$0.00	$1,042.45	$974.49	$25.00	$5,189.25	$5,189.25	3.36	3.36
296	140005	$3,771.37	$3,220.02	$714.90	$700.39	$100.00	$8,506.68	$5,286.66	6.08	3.78
411	73106	$1,934.21	$1,741.18	$389.55	$1,704.75	$70.00	$5,839.34	$4,098.51	7.99	5.61
413	86568	$2,000.87	$2,875.77	$180.61	$224.26	$100.00	$5,381.51	$2,505.74	6.22	2.89
427	86328	$1,757.30	$0.00	$341.12	$711.04	$0.00	$2,809.46	$2,809.46	3.25	3.25
456	118857	$2,753.23	$0.00	$299.39	$663.00	$0.00	$3,715.62	$3,715.62	3.13	3.13
463	118680	$2,538.58	$2,687.19	$774.75	$797.00	$55.00	$6,852.52	$4,165.33	5.77	3.51
480	104976	$2,629.16	$567.06	$685.49	$618.60	$25.00	$4,525.31	$3,958.25	4.31	3.77
530	118126	$1,365.50	$0.00	$591.01	$656.39	$25.00	$2,637.90	$2,637.90	2.23	2.23
Sum–CNG	1083317	$23,544.67	$11,091.22	$5,190.27	$7,107.12	$457.00	$47,389.93	$36,299.06	44.69	33.88
Avg. CNG (Sum/10)	108331.7	$2,354.47	$1,109.12	$519.03	$710.71	$45.70	$4,738.99	$3,629.91	4.47	3.39
Gasoline Vehicles										
261	138854	$3,563.05	$0.00	$177.59	$626.87	$0.00	$4,367.51	$4,367.51	3.15	3.15
329	139906	$2,773.13	$596.88	$444.25	$637.94	$104.87	$4,557.07	$3,960.19	3.26	2.83
376	114848	$2,791.46	$718.64	$548.19	$776.00	$110.00	$4,944.29	$4,225.65	4.31	3.68
492	119966	$4,283.73	$1,951.70	$819.21	$610.80	$80.00	$7,745.44	$5,793.75	6.46	4.83
521	123297	$3,693.42	$1,322.65	$1,078.45	$620.19	$70.00	$6,784.71	$5,462.06	5.50	4.43
528	118841	$3,281.99	$364.00	$1,429.71	$788.19	$77.50	$5,941.39	$5,577.41	5.00	4.69
533	132281	$4,306.91	$0.00	$1,502.71	$713.59	$430.50	$6,953.71	$6,953.71	5.26	5.26
545	131202	$3,073.28	$1,169.31	$412.70	$674.39	$105.00	$5,434.68	$4,265.37	4.14	3.25
676	116400	$2,931.08	$0.00	$1,150.07	$534.79	$215.00	$4,830.94	$4,830.94	4.15	4.15
692	136135	$3,846.14	$1,181.67	$123.20	$352.20	$35.00	$5,538.21	$4,356.54	4.07	3.20
Sum–gasoline	1271730	$34,544.19	$7,304.85	$7,686.08	$6,334.96	$1,227.87	$57,097.95	$49,793.13	45.28	39.47
Ave. gasoline (Sum/10)	127173	$3,454.42	$730.49	$768.61	$633.50	$122.79	$5,709.80	$4,979.31	4.53	3.95

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13. ABSTRACT *(Maximum 200 words)*

This report describes a fleet study conducted over a 12-month period to evaluate the operation of dedicated compress natural gas (CNG) Ford Crown Victoria sedans in a taxicab fleet. In the study, we assess the performance and reliability of the vehicles and the cost of operating the CNG vehicles compared to gasoline vehicles. The study results reveal that the CNG vehicles operated by this fleet offer both economic and environmental advantages. The total operating costs of the CNG vehicles were about 25% lower than those of the gasoline vehicles. The CNG vehicles performed as well as the gasoline vehicles, and were just as reliable. Barwood representatives and drivers have come to consider the CNG vehicles an asset to their business and to the air quality of the local community.

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